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03/14/2002 12:00 PM

To: Robert Sanchez/R3/USEPA/US@EPA
Subject: SPECTRON 6 March 2002 Meeting Notes and Conceptual HRC Costing

<<6 March 02 Meeting Notes.doc>> <<SPECTRON_Regenesis Software ver 3US.xls>>

Rob;

Please find attached my draft notes from our 6 March 2002 meeting. Also attached is conceptual costing for HRC groundwater remediation in selected areas in the bedrock and shallow groundwater at SPECTRON. Dave Pohl has not reviewed this yet but I wanted to get it to you as soon as I could. I would like to highlight the following key points:

i. These are conceptual costs for one remediation technology. Evaluation of other remediation approaches and a more thorough evaluation of this approach should be conducted.
ii. Highly contaminated groundwater discharges up into the shallow overburden groundwater at SPECTRON, which minimizes the benefit gained from conducting shallow groundwater remediation before the bedrock groundwater contamination is addressed.
iii. The SPECTRON site is highly contaminated with dissolved phase and DNAPL contamination in saturated overburden and fractured bedrock. The combination of fractured rock and DNAPL makes the conditions complex but does not necessarily preclude the use of in situ remediation technologies for source mass reduction. However, the remediation objective should not be to meet a specific groundwater concentration, which may not be an attainable goal at this site.

Please give me a call if you have any questions or would like to discuss this further.

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6 March 02 Meeting Notes.dc SPECTRON_Regenesis Software ver 3U!

6 March 2002 ~1:00 – 4:00 Draft Meeting Notes and Follow Up Costing

Attendees: Rob Sanchez, Tom Cornuet, and Dave Pohl (end of meeting)

Discussion Topics

1. **Discussed Ohio and Virginia HRC In Situ Bioremediation (ISB) projects.**

2. **Discussed responses to Robs questions listed in his 27 February 2002 Letter. The questions and responses are provided below.**

   a. Will HRC be effective on the type of contaminants at the site?
      Yes, on dissolved phase. It would also increase rate of DNAPL dissolution. The difficult issue is the unknown amount of VOC mass present at the site.

   b. Are the concentrations of contaminants too high for HRC to work effectively to reduce contamination?
      Available literature indicates probably not.

   c. Are there other treatments that are better suited than HRC for the contaminants at Spectron?
      Others that should be considered:
      - *ISB with sodium lactate.*
      - *Chemical oxidation.*
      - *Steam injection or surfactant flushing.*

   d. Are the conditions (I.E., permeability, etc.) at Spectron favorable to use of HRC or other treatments?
      The combination of fractured rock and DNAPL makes the conditions complex but does not necessarily preclude the use of in situ remediation technologies for source mass reduction. However, the remediation objective should not be to meet a specific groundwater concentration, which may not be an attainable goal at this site.

   e. Should HRC be applied through many vertical wells at highly contaminated areas, or should a broader site-wide application through horizontal wells be used? Which is most cost effective?
      Horizontal wells installed into the fractured metamorphic bedrock at this site would be difficult and expensive. HRC has been applied with vertical wells, vertical direct-push, and horizontal direct-push methods. The best approach for HRC application at this site would probably be using vertical open-hole wells installed at highly contaminated areas with pressurized packer injection of HRC into the bedrock (Earth Data, Inc. has experience with this). If shallow overburden groundwater treatment were needed, direct-push injection HRC application focused in highly contaminated areas where the saturated overburden is thickest would probably be the best approach.

f. Can a horizontal well be placed at the top of the low permeability layer?
   Probably not realistically.

g. Will the contaminants in the vadose zone be impacted if HRC is used? Does HRC create a biological biosparge effect, which may require collection of off gases from the vadose zone?
   No. No.

3. **Discussed summary of notes from last meeting 13 February 2002, highlights are shown below:**
   a. Unsaturated soil remediation is difficult to conduct using in situ methods due to several reasons. An engineered permeable cap with focused soil removal was recommended.

   b. Disadvantages of conducting horizontal well biosparging in the shallow groundwater were discussed.

   c. The highly contaminated bedrock groundwater discharges upward into the shallow groundwater. This minimizes the benefits gained from shallow groundwater remediation efforts conducted before the bedrock groundwater contamination is addressed. Therefore groundwater remediation efforts would be most effective targeted in the bedrock groundwater rather than in the shallow unconsolidated soil groundwater. Much progress has been made in the remediation of highly contaminated aquifers that contain DNAPL. Remediation technologies that should be considered for this site include:
      i. In Situ Chemical Oxidation using peroxide, magnesium peroxide or some other effective oxidizer.
      ii. In Situ Anaerobic Reductive Dechlorination Bioremediation using HRC, sodium lactate, or some other effective electron donor.
      iii. Chemical Reduction using Bimetallic Nanoscale Particles (BNP).
      iv. Steam or Surfactant injection.

   d. Suggested components of the Onsite Soil and Shallow Groundwater ROD included the followng:
      i. Engineered permeable cap
      ii. Localized soil hot spot excavation
      iii. Containment system monitoring program upgrade
      iv. Include language stating the bedrock is the major source of contamination and site risk and needs to be addressed beyond the current containment system.

4. **Discussed potential remediation technologies for the bedrock groundwater and provided Rob with pertinent references and vendor information.**

5. **Discussed the EPA and WESTON budget status and need for additional authorization.**

6. **Discussed the need for conceptual level costing for HRC remediation for the site. Conceptual costing for bedrock and shallow groundwater HRC application was conducted after the meeting. Costing assumptions are summarized below and the Regenesis, Inc. HRC costing sheet is attached.**

   a. Shallow Groundwater Conceptual Costing Assumptions:
      i. 75 ft x 150 ft area in thicker highly contaminated portion of the site between G-7 and MW-11
      ii. Three HRC geoprobe applications conducted over 5 years
      iii. Saturated thickness/treatment interval = 15 ft (~5 to 25 ft bgs)
      iv. Hydraulic conductivity = 1 ft/day
      v. Porosity = 0.2
      vi. Groundwater gradient = 0.035
      vii. Concentrations: PCE, TCE, 1,1,1-TCA, and methylene chloride=1% solubility
      viii. Objective is mass reduction and assumes no recontamination from bedrock
         - **~$150,000 per application**
         - **~$450,000 for three applications over 5 years**

   b. Bedrock Groundwater Conceptual Costing Assumptions:
      i. 75 ft x 225 ft area in the highly contaminated portion of the site along the creek and upgradient of G-39 and VW-2
      ii. Three HRC pressure packer injection applications conducted in 9 bedrock wells over 5 years
      iii. Saturated thickness/treatment interval = 45 ft (~30 to 75 ft bgs)
      iv. Hydraulic conductivity = 0.3 ft/day
      v. Porosity = 0.05
      vi. Groundwater gradient = 0.01
      vii. Concentrations: PCE, TCE, 1,1,1-TCA = 10%, methylene chloride=5% solubility
      viii. Objective is mass reduction
         - **~$80,000 design and well installation**
         - **~$170,000 per application**
         - **~$590,000 for design, installation, and three applications over 5 years**

   c. Additional notes:
      i. These are conceptual costs for one remediation technology. Other remediation approaches and a more thorough evaluation of this approach should be conducted.
      ii. Highly contaminated groundwater discharges up into the shallow overburden groundwater, which minimizes the benefit gained from conducting shallow groundwater remediation before the bedrock groundwater contamination is addressed.
      iii. The SPECTRON site is highly contaminated with dissolved phase and DNAPL contamination in saturated overburden and fractured bedrock. The combination of fractured rock and DNAPL makes the conditions complex but does not necessarily preclude the use of in situ remediation technologies for source mass reduction. However, the remediation objective should not be to meet a specific groundwater

concentration, which may not be an attainable goal at this site.

Technology
Overview Report

TO-96-04

GWRTAC
O
SERIES

Air Sparging

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October 1996

Prepared For:

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FOREWORD

About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies to clean up contaminated groundwater.

Established in 1995, GWRTAC is operated by the National Environmental Technology Applications Center (NETAC) in association with the University of Pittsburgh's Environmental Engineering Program through a Cooperative Agreement with the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). NETAC is an operating unit of the Center for Hazardous Materials Research and focuses on accelerating the development and commercial use of new environmental technologies.

GWRTAC wishes to acknowledge the support and encouragement received for the completion of this report from the EPA TIO.

About "O" Series Reports

This report is one of the GWRTAC "O" Series of reports developed by GWRTAC to provide a general overview and introduction to a groundwater-related remediation technology. These overview reports are intended to provide a basic orientation to the technology. They contain information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts are made to independently confirm or peer review the resources used.

Disclaimer

GWRTAC makes no warranties, express or implied, including without limitation, warranty for completeness, accuracy, or usefulness of the information, warranties as to the merchantability, or fitness for a particular purpose. Moreover, the listing of any technology, corporation, company, person, of facility in this report does not constitute endorsement, approval, or recommendation by GWRTAC, NETAC, or the EPA.

ABSTRACT

This technology summary report provides a brief overview of an environmental remediation technology, including an introduction to its general principles, reported applicability and utilization, and cited advantages/disadvantages. This report is provided for informational purposes only and is not intended as a state-of-the-art peer reviewed analysis of this technology. Information used in the preparation of this report was gathered from periodicals, through Internet searches, and in some cases, from personal communications with involved parties. No attempt was made to confirm the veracity of interpretations and/or representations made in any information resource used. In addition, *listing of any technology, corporation, company, person, or facility does not constitute endorsement,* approval, or recommendation by National Environmental Technologies Application Center (NETAC).

Air sparging involves injecting a gas (usually air/oxygen) under pressure into the saturated zone to volatilize groundwater contaminants and to promote biodegradation in saturated and unsaturated soils by increasing subsurface oxygen concentrations. Volatilized vapors migrate into the vadose zone where they are extracted via vacuum, generally by a soil vapor extraction system. The term biosparging is sometimes used interchangeably with air sparging to highlight the bioremediation aspect of the treatment process or can refer to situations where biodegradation is the dominant remedial process, with volatilization playing a secondary role.

Air sparging has been used to address a broad range of volatile and semivolatile groundwater and soil contaminants including gasoline and other fuels and associated BTEX components and chlorinated solvents. According to information reviewed, sites with relatively permeable, homogeneous soil conditions favor the use of air sparging due to greater effective contact between sparged air and the media being treated and effective migration/extraction of volatilized vapors. Other appropriate site conditions mentioned include relatively large saturated thicknesses and depths to groundwater. These factors both control the area of influence of a sparging well, and if saturated thickness/depth to groundwater are small, the number of wells required for adequate coverage may become cost-prohibitive.

Several applications of air sparging technology are discussed which report that, when applied properly, this technique can be a cost effective method for meeting remedial objectives within reasonable time frames. Air sparging reportedly can be more effective than pump-and-treat methods since "contaminants desorb more readily into the gas phase than into groundwater" and since increased volatilization can overcome the diffusion-limited extraction of VOCs from groundwater. Another reported advantage of air sparging is that in contrast to vapor extraction, it can be used to treat contamination in the capillary fringe and below the water table.

Bioventing, also a modification of vapor extraction technology, is briefly contrasted with air sparging. With bioventing, extraction or injection of air into the vadose zone increases subsurface oxygen concentration, promoting bioremediation of unsaturated soil contaminants. This technique is applicable to all biodegradable contaminants, but has been applied most frequently and reportedly most successfully to sites with petroleum hydrocarbon contamination.

This document was prepared for distribution by the Ground-water Remediation Technologies Analysis Center (GWRTAC). GWRTAC is being operated by NETAC under a Cooperative Agreement with the United States Environmental Protection Agency's (EPA) Technology Innovation Office (TIO).

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1.0 INTRODUCTION

1.1 GENERAL

Air sparging is an *in situ* groundwater remediation technology that involves the injection of a gas (usually air/oxygen) under pressure into a well installed into the saturated zone. Air sparging technology ***extends the applicability of soil vapor extraction to saturated soils and groundwater*** through ***physical removal of volatilized groundwater contaminants and enhanced biodegradation*** in the saturated and unsaturated zones. Oxygen injected below the water table volatilizes contaminants that are dissolved in groundwater, existing as a separate aqueous phase, and/or sorbed onto saturated soil particles. The volatilized contaminants migrate upward in the vadose zone, where they are removed, generally using ***soil vapor extraction techniques***. This process of moving dissolved and non-aqueous volatile organic compounds (VOCs), originally located below the water table, into the unsaturated zone has been likened to an *in situ*, saturated zone, air stripping system (4). In addition to this air stripping process, air sparging also promotes biodegradation by increasing oxygen concentrations in the subsurface, stimulating aerobic biodegradation in the saturated and unsaturated zones.

Air sparging systems must be designed with air flow rates and pressures to provide adequate coverage of the area of contamination, while minimizing the potential for uncontrolled releases of contaminated vapors to the atmosphere, into buildings, etc. ***Off-gas treatment*** may be required for extracted vapors, depending on site conditions and system design, although adjusting injection/ extraction rates can significantly reduce, and in some cases eliminate, the need for surface vapor treatment. The presence of non-biodegradable volatile contaminants generally mandates off-gas treatment (1, 4).

1.2 MODIFICATIONS/VARIATIONS

Horizontal well technology can be effectively applied to air sparging/vapor extraction technology to allow increased access to the subsurface. This greater access will provide for more efficient delivery of air, removal of adsorbed VOCs, and recovery of vapors. The potential for aquifer clogging is also reduced since a larger area is being treated (10). It has also been reported that air sparging can be used as a ***hydraulic containment*** technology, with injected air creating an "air sparge curtain" that can mitigate downgradient transport of contaminants (4). Air sparging can reportedly be combined with natural attenuation and pump-and-treat techniques, increasing the rate of cleanup when compared to use of these techniques alone.

Other variations on the basic air sparging system can be used to increase volatilization or stimulate biodegradation including:

- Soil heating;
- Injection of heated air;
- Injection of steam;
- Nutrient amendments (in gas phase);
- Alcohol flooding (3, 4, 12).

In addition to these enhancements to air sparging technology, ***other modifications*** that may improve performance include varying the geometry of injection and extraction well networks, combining *vertical and horizontal* wells, *and installing horizontal wells perpendicular to groundwater flow* (3).

1.3 BIOSPARGING

Biosparging, sometimes used interchangeably for air sparging, highlights the contribution of enhanced bioremediation to the air sparging process. This term also has been applied when biodegradation is the main remediation process at work at a particular site, and when vapor extraction is not performed, and bioremediation is the sole treatment mechanism (4).

2.0 APPLICABILITY

In general, air sparging is applicable at sites where groundwater and/or saturated soils are contaminated with ***volatile, semivolatile, and/or nonvolatile aerobically biodegradable*** organic contaminants. Air sparging can be applied to situations in which dewatering (to allow the application of vapor extraction to residually contaminated soils) is not feasible. Examples of such situations include sites with high yield aquifers and thick smear zones. When dense non-aqueous phase liquids (DNAPLs) are present, deep penetration of non-aqueous contamination may require a level of dewatering that would not be practical. (2, 4, 12).

2.1 CONTAMINANTS

As noted above, various volatile, semivolatile, and nonvolatile organic contaminants in dissolved, free-phase, sorbed, and vapor phases can be treated using air sparging. Air sparging is applicable for the treatment of ***less volatile and/or tightly sorbed chemicals that could not be remediated using vapor extraction alone.***

Contaminants affected by the volatilization and biodegradation processes of air sparging include (1, 2, 4, 11):

- Various fuels, such as gasoline, diesel, jet fuel, etc.;
- Oils and greases;
- BTEX components;
- Chlorinated solvents (PCE, TCE, DCE, etc.).

In addition, one patented air sparging system (BioSparge from Hayward Baker Environmental, Inc.) uses an ozone generator with the standard air sparging technique to extend the capabilities of the technology to chlorinated phenols (PCP), alcohols, ketones, and other industrial solvents The injected ozone breaks the chlorine bonds, facilitating biodegradation of the resulting compounds (4).

Billings and Associates, Inc. has reported that their Subsurface Volatilization and Ventilation System (SVVS™) "can be used to treat heavy metals in groundwater by raising redox potential and inducing metals to precipitate" (11), but this technique is not known to have been applied in field studies (4).

2.2 SITE CONDITIONS

Successful use of air sparging technology depends on the ability of the system to effectively deliver air to the treatment area and the ability of the subsurface materials to effectively transmit the air (3). Therefore, site conditions that ***favor the successful application of air sparging technology*** include relatively coarse-grained (moderate to high permeability) homogeneous overburden materials that foster "effective contact" between air and media being treated. Fine-grained, low permeability soils limit the migration of air in the subsurface, thereby limiting the effectiveness of air delivery and vapor recovery. In addition, heterogeneity, due to lithologic variations or fractures, may limit the effectiveness of this technology. For example, one or more low permeability layers located between the water table and the ground surface would restrict the ability of the vapor extraction wells to remove volatilized contaminants migrating upward from the saturated zone (2, 3).

In addition, ***relatively large saturated thicknesses and depths to groundwater greater than 5 feet*** may also be required for successful application of this technology. The length of the saturated thickness and the depth below the water table at which air is injected are the factors that determine the area of influence of a sparging well. Air sparging as a remediation technology may be impractical/ unfeasible if either of these distances is small since the number of injection points that would be required to ensure effective delivery of air to the entire contaminated area would be cost-prohibitive (1).

3.0 METHODOLOGY

Implementation of a safe and successful air sparging project requires a ***detailed site investigation including site-specific determination of air flow patterns in the unsaturated zone and conditions relating to the feasibility of bioremediation*** (nutrient concentrations, contaminants at levels toxic to microbes, etc.) (2). Following the site investigation, a pilot-scale test is generally performed to assess assumptions to be used in the design of the full-scale remediation system and to determine effective air flow rates and injection pressures.

There are several variations of the basic air sparging/vapor extraction process, many of which are patented. The description that follows is a general synthesis of information reviewed concerning implementation of this technology.

3.1 AIR SPARGING/VAPOR EXTRACTION SYSTEMS

An air sparging system consists of a ***network of air injection ("sparging") wells installed into the saturated zone and a network of vapor extraction wells installed into the vadose zone***. The network of injection wells is designed so that all of the area requiring treatment is effectively aerated. This typically involves establishing overlapping zones of influence for the sparging well network (4).

Air compressors are used to deliver oxygen under pressure, and ***vacuum pumps*** (utilizing separate piping systems) are used to create negative pressure for removal of vapors (12). An aboveground process control system is used to monitor and adjust the air delivery and removal equipment. Additional aboveground equipment also may include a gas-liquid separator connected to the extraction well network and a vapor treatment system (see below) (4). ***Flow rates and pressures of injected air*** are based on site conditions characterized during the investigation phase of the project and refined during pilot scale testing. These rates can be adjusted during full-scale remediation to accommodate observed results and increase remediation efficiency.

3.2 VAPOR EXTRACTION VS. BIOREMEDIATION RATES

Vapor extraction removes the more volatile (easily strippable) contaminants and removes a greater relative portion of contaminants during the initial stages of remediation. When the contaminants that already existed in a vapor phase and the easily volatilized contaminants have been removed, the rate of vapor removal decreases and the rate of biodegradation increases, becoming a dominant factor in later stages of remediation. This is due to the fact that c***ontaminant removal during latter stages of remediation is more a result of biodegradation of less volatile, more strongly adsorbed contaminants*** (2, 4). The relative rates of air stripping versus bioremediation at any point in the remediation process depend on factors such as site geology/hydrogeology, contaminant characteristics, and the design of the air sparging system (1).

3.3 VAPOR TREATMENT

If vapor treatment is required, the extraction wells are connected to an aboveground treatment system (bioreactor, activated carbon, etc.). Vapor treatment systems may be required more frequently in initial project stages until bioremediation becomes the dominant treatment process in effect at a site (see above) (11). It has been stated that ***"air emissions can be favorably controlled within regulatory limits by adjusting the rate of air injection and extraction.*** (11 Adjustments can also be with regard to areas receiving negative and positive air pressure to concentrate remediation efforts in specific areas of the site (12). Cycling on and off of sparging wells, at periods determined by dissolved oxygen levels in groundwater and volatile compounds in the unsaturated zone can enable the maximizing of biodegradation as opposed to air stripping, possibly minimizing the amount of air requiring treatment (1).

3.4 DESIGN CONSIDERATIONS

Factors to consider when designing an air sparging system include:

- Site geologic and hydrogeologic conditions;
- Type and distribution of contaminant(s);
- Air flow rates and injection pressures;
- Injection interval (horizontal and vertical);
- Parameters affecting the viability of microorganisms and their ability to successfully biodegrade contaminants at the site (7).

Potential health and safety concerns associated with the injection of air into the subsurface to increase volatilization rates include:

- Vapor migration and release to the surface and/or accumulation in buildings, utility trenches, etc.;
- Groundwater mounding (due to displacement of water by injected air) causing migration of the groundwater plume;
- Increased mixing (due to air injection) and so increased mass transfer of contaminants to groundwater and vapor phases (2).

To prevent these situations, the air sparging system must carefully monitor/control air injection rates, utilize a vapor extraction system, and may, if required, implement a groundwater containment program (1, 2). To achieve groundwater containment, a series of sparging wells can be installed downgradient of the treatment area to prevent off-site migration of contaminated groundwater (4).

4.0 TECHNOLOGY PERFORMANCE

NOTE: The following information is provided for informational purposes only.

GWRTAC (EPA TIO, NETAC, CHMR, and the University of Pittsburgh) neither endorses nor in any way recommends the companies discussed below. No effort has been made, nor will be made, to verify the accuracy of the information provided, or to assess the validity of any claims about the companies. GWRTAC makes no warranties, expressed or otherwise, without limitation or liability, for the completeness, accuracy, or usefulness on the information provided.

It has been reported that "most economically-feasible vapor extraction-based system designs achieve remediation in the 0.5 to 3 year time frame (2)." Costs for air sparging vary with the specific methodology/modifications used, whether of not air is extracted, and whether or not (and the extent of) aboveground treatment of vapors is required. Presented below are selected examples of remedial performance and cost information for sites utilizing air sparging.

4.1 BIOSPARGE™ (HAYWARD BAKER ENVIRONMENTAL, INC.)

Studies of the BioSparge™ air sparging/vapor extraction system indicated that up to 75% of contaminant removal was accomplished by *in situ* bioremediation, although a greater portion of the more volatile compounds were removed through vapor extraction. ***Treatment time estimates for this system are reduced to 6 to 24 months*** for most sites since less volatile contaminants are biodegraded instead of extracted as vapor. The addition of bioremediation processes makes application of this technology ***more favorable for the remediation of less volatile contaminants like diesel fuel and waste oils*** (4).

4.2 NATIONS GROUNDWATER ASSOCIATES

At another site where existing monitoring wells were converted to sparging wells, ***air sparging/ vacuum extraction technology applied for 18 months reduced hydrocarbon concentrations in groundwater more than 99%*** (from levels "thousands of times higher than California mandated levels"). Pump-and-treat methods were estimated to have taken 7 to 15 years to achieve similar results. ***Costs for this 18-month period are below $18,000. Estimated of costs for alternative treatment methods of similar sites range from $200,000 to $500,000*** (6).

4.3 SVVS™ (BILLINGS AND ASSOCIATES, INC.)

The SVVS™ air sparging/vapor extraction system was evaluated under EPA's Superfund Innovative Technology Evaluation (SITE) Program between April 1993 and April 1994 (11, 12). Results indicated an ***overall 80.6% reduction in total concentrations of seven "critical VOCs"*** (BTEX, TCE, PCE, 1,1-DCE) after the one-year operation period. The average sum of these VOCs in vadose soils was reduced during the demonstration from 341.5 mg/kg to 66.2 mg/kg. Contaminant reductions in matched boreholes, tested before and after remediation activities, ranged from 71% to 99%. These results were an indication that the system performed relatively uniformly, with no "significant untreated areas..., regardless of initial VOC concentrations or lithology (11)." Groundwater performance criteria could not be evaluated due to concentrations of contaminants below detection limits for the entire treatment period. However, ***VOC concentrations in saturated soils were reduced by 99.3%***, which is comparable to vadose zone reductions.

The cost of full-scale remediation for this demonstration was $220,737, assuming that no off-gas treatment was required, with a total of 21,300 cubic yards of soil treated. Based on these numbers, the ***cost per cubic yard of soil remediated was $10.36***. A breakdown of major cost categories is presented below:

- Site preparation, 28%;
- Analytical services, 27%;
- Residuals/waste shipping, handling, storage, and disposal, 13%;
- Labor, 9%.

A cost increase of approximately 43% was predicted if off-gas treatment was required, depending on site conditions and the treatment process used (11).

4.4 VAPOR EXTRACTION/AIR SPARGING VIA HORIZONTAL WELLS (SAVANNAH RIVER SITE)

The performance of vapor extraction/air sparging (or *in situ* air stripping) using a pair of horizontal wells (one extraction well above one injection well) was demonstrated during FY90 a the Savannah River Site in Aiken, South Carolina (3, 9, 10). Results indicated that ***over the 20-week period of operation, the system removed approximately 16,000 pounds of VOCs*** through the extraction well. It was estimated that this "rate was equivalent to 11 pump-and-treat wells pumping at a rate of 500 gallons per minute (10)." Analysis of soil samples showed that aerobic biodegradation destroyed an even larger quantity of contamination. The rate of contaminant removal by soil vapor extraction alone, estimated at 109 pounds/day, increased to 130 pounds/day with the addition of air through the sparging well (3). Table 1 summarizes results observed at the Savannah River Site (3).

TABLE 1. SUMMARY OF RESULTS AT THE SAVANNAH RIVER SITE

Contaminant	Initial Concentration	Final Concentration	Initial Concentration	Final Concentration
TCE	500-1,800 µg/L	10-1,031 µg/L	1.26-16.32 mg/kg	0.67-6.29 mg/kg
PCE	85-184 µg/L	3-124 µg/L	0.03-8.75 mg/kg	0.44-1.05 mg/kg

Cost analysis of this technology demonstration indicated a ***cost per pound of VOC removed at $15.59***. A cost breakdown by expense category is as follows:

- Equipment, 10%;
- Site costs, 2%;
- Labor, 25%;
- Consumables, 63% (3).

A comparable system of four vertical well pairs and a pump-and-treat extraction well and associated processing system was estimated to cost approximately $27.07 per pound of VOC removed. The increased rate of contaminant removal using the air sparging/vapor extraction system compared to competing technologies can outweigh the higher capitol costs, making this system more cost effective (9). ***A cost-benefit analysis of the horizontal well air sparging/vapor extraction system estimated a 40% cost reduction over a pump-and-treat/soil vapor extraction system*** (3, 9).

5.0 TECHNOLOGY ADVANTAGES

Applied properly, air sparging can be a low-maintenance *in situ* remediation method, requiring minimal disturbance to on-going site activities, while providing a reasonable time frame to achieve cleanup goals. By eliminating the need for extraction and surface treatment of groundwater, air sparging can be a cost effective alternative to pump-and-treat remediation systems. Specific advantages of air sparging are listed below.

- It is possible that ***existing monitoring wells could be used for air sparging*** (6);
- Air sparging overcomes a major limitation associated with pump-and-treat — the ***decline in extractedVOC concentrations "over time due to diffusion-limited flow rates"***(9);
- Another advantage of air sparging over pump-and-treat is that "***contaminants desorb more readily into the gas phase than into groundwater*** (4)";
- Air sparging can be used to ***treat contamination in the capillary fringe and/or below the water table*** (in contrast to soil vapor extraction techniques);
- Because of the low operation and maintenance costs of this technology, it may be "particularly effective when ***large quantities of groundwater*** must be treated"(4).

6.0 TECHNOLOGY LIMITATIONS

Site conditions to which air sparging could not effectively or economically be applied include:

- ***Contaminants that form complexes with the soil matrix***, decreasing volatilization rates;
- ***Fine-grained, low-permeability soils*** that would decrease air flow through groundwater and in the vadose zone;
- Lithology including a ***low-permeability layer overlying the aquifer***, which would prevent volatilized vapors migrating from groundwater to be effectively captured by vapor extraction wells;
- Heterogeneous soils may cause ***channeling*** (preferential movement of air through high conductivity layers, and possibly away from the area of contamination) or other complex air flow conditions that may be difficult to predict and/or control (2, 4);
- Sites where ***contaminated groundwater is less than 5 feet BGS*** (as noted in Section 2.2) or where the saturated thickness is small may require a prohibitive number of wells to ensure full coverage of the area of concern.

An additional limitation of air sparging systems is the planning and design/control necessary to accomplish sufficient air delivery (number of wells and injection pressures) while ***preventing harmful/ unwanted effects*** such as off-site vapor migration, groundwater mounding resulting in enhanced plume migration, channeling, and aquifer clogging. Aquifer clogging or plugging may occur when increased iron precipitation or biomass accumulation caused by oxygen injection changes aquifer characteristics (4).

7.0 COMPARISON TO BIOVENTING

Bioventing is related to air sparging in that it is a modification of soil vapor extraction technology, and it involves ***stimulation of indigenous microorganisms through increased oxygen content*** in the subsurface (1). However, bioventing involves wells installed into the vadose zone and treats vadose zone soil contamination. In this technology, increased air movement within the subsurface, from air injection or withdrawal, brings oxygen into the area of contamination. This increase in oxygen content of the soil, often a limiting factor in the rate of aerobic biodegradation, stimulates biodegradation of contaminants by naturally-occurring microorganisms. To optimize biodegradation rates (the goal of bioventing) soil oxygen content may need to be maintained at some constant value (2 to 4 % by volume)(2, 5).

Bioventing technology can be modified to address contamination by chlorinated solvents by adding vapor extraction and treatment components. Creation of an artificial smear zone, or groundwater depression to expose a natural smear zone, may be implemented with bioventing to provide increased exposure to contaminants that can then be degraded. In addition, heated air can be injected in cooler climates or seasons to increase microbial activity.

Air flow rates in bioventing are generally much lower than in soil vapor extraction to maximize biodegradation rates and minimize volatilization rates. This may reduce or eliminate the need for extracted air treatment, resulting in significant cost savings (2, 5).

System instrumentation for bioventing is very similar to that of soil vapor extraction, with vacuum pumps to inject air. In fact, soil vapor extraction systems have been converted, with minimal modifications, to bioventing applications. Bioventing can be used to treat any aerobically biodegradable contaminant volatile, semivolatile, and non-volatile organics. This includes gasoline, diesel, kerosene, fuel oils, chlorinated solvents, organochlorine herbicides, pesticides, phenols, PAHs, and others. Amendments such as nutrients (commonly phosphorus or ammonia), methane, and moisture may be injected to further stimulate the growth of microorganisms and so the rate of biodegradation (1, 2, 5).

Bioventing is predicted to be most successful to sites where the water table is below 10 feet BGS. This technology is not applicable to treatment of surficial soils (between 0 and 2 feet) unless the surface of the site is capped. Capping may also allow the technique to be used at sites where the water table is shallower than 10 feet (1). As with air sparging, this technique has not been effective at sites with low permeability clay soils or highly heterogeneous soils, due to the difficulties in effectively delivering air to the entire area to be treated (4, 5).

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